CHAPTER 5
ELECTRICAL SYSTEMS

5-1. Electrical design criteria

The design of electrical service and distribution systems should be consistent with industry standards such as those produced by the Institute of Electrical and Electronics Engineers (IEEE), NFPA, and the American National Standards Institute (ANSI) as well as applicable DoD guidelines and standards. System designs should make use of utility-grade equipment and components to support reliability and maintainability. While there is no formal standard definition, utility grade is generally distinguished from commercial grade by construction and features that support extended life expectancy, tolerance of adverse environments, and ease of access and disassembly for testing and maintenance. Examples of the difference are shown in table 5-1.

Table 5-1. Features of utility-grade and commercial-grade equipment

Utility Grade	Commercial Grade
Drawout-mounted protective devices with tested surge withstand capability for power system relaying	Surface-mounted relays with no tested withstand ratings
Switchgear complying with Underwriters Laboratories Inc. (UL) Standard 1558 construction standards	Switchboards complying with UL Standard 891 construction standards
Low-voltage power circuit breakers rated to ANSI Standard C37 and UL Standard 1066	Molded-case or insulated-case circuit breakers rated to UL Standard 489

5-2. Applicable electrical codes and standards

The following specific standards are of particular concern in the design of electrical systems to support the LVD concept:

a. TM 5-689, ADP/Computer Electrical Installation and Inspection for Command, Control, Communications, Computer, Intelligence, Surveillance, and Reconnaissance (C4ISR) Facilities.

b. TM 5-690, Grounding and Bonding in Command, Control, Communications, Computer, Intelligence, Surveillance, and Reconnaissance (C4ISR) Facilities.

c. TM 5-693, Uninterruptible Power Supply Selection, Installation, and Maintenance for Command, Control, Communications, Computer, Intelligence, Surveillance, and Reconnaissance (C4ISR) Facilities

d. NFPA 70, National Electrical Code (NEC).

e. NFPA 70B, Recommended Practice for Electrical Equipment Maintenance.

f. IEEE Standard 242, Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems.

g. IEEE Standard 493, Recommended Practice for Design of Reliable Industrial and Commercial Power Systems.

h. IEEE Standard 1100, Recommended Practice for Powering and Grounding Sensitive Electronic Equipment.

i. ANSI C37, Standards Collection: Circuit Breakers, Switchgear, Substations, and Fuses.

5-3. Segregation and separation

Segregation and separation of power generation, power distribution, equipment and controls is necessary to provide the ability of the system to reliably and safely function in the event of a catastrophic event.

a. Figure 5-1 shows one possible arrangement of utility service, standby generation, and power distribution for the example facility. In this case, each peripheral zone bus has local standby generation adequate to carry the contingency load on that bus. The load on each bus consists of the demand load of that zone of the building plus a share of the command center demand load. Loss of a single peripheral zone results in a loss of only one of the four feeders to the command center. These feeders should be routed entirely within the zone of origin until they cross the barrier wall into the command center.

(1) Within the command center, it is assumed that physical segregation of utility supplies to protect from explosive threat is not necessary. However, it remains critical to provide adequate segregation internal to equipment to prevent an arcing fault from propagating to affect multiple sources.

(2) Figure 5-1 shows a possible arrangement of transfer equipment when the command center loads are served from a 2N uninterruptible power supply (UPS) and mechanical system. The normally open tie circuits isolate the "A" buses from the "B" buses so that no single component failure can affect both sides.

b. Segregation of controls is also critical. A significant advantage of the distribution scheme shown in figure 5-1 is that independent transfer controls can be provided for the redundant portions of the system. Each service has an automatic bus transfer scheme that starts the generator and transfers the bus on failure of the utility source; there is no need for common controls between services. Similarly, within the command center, the "A" and "B" distribution is provided with separate automatic transfer controls. Redundancy of the electrical system should be selected to match the redundancy of the mechanical and other loads it serves. It may be tempting to increase the degree of redundancy by providing tie circuits between the services or by automating the tie breakers between the "A" and "B" buses within the command center. This would result in higher calculated availability due to more combinations of paths to the load but would require that control systems cross the segregation boundaries established for the distribution. This risks actually lowering availability by complicating the control scheme and introducing the potential for a control system failure to produce common-mode failure of multiple distribution paths.

5-4. Protective device coordination

Electrical systems in all areas of the C4ISR facility should be designed for selective coordination of overcurrent and other modes of protection according to IEEE Standard 242. It is particularly critical that the distribution system within the command center zone be selective to prevent a single internal fault from propagating upstream to the feeders that supply this zone from the peripheral zones. Electrical system reliability calculations verifying compliance with mission requirements generally assume that protective devices are selectively coordinated; failure to design for complete selectivity will result in the actual reliability of the command center service being significantly lower than the calculated values.

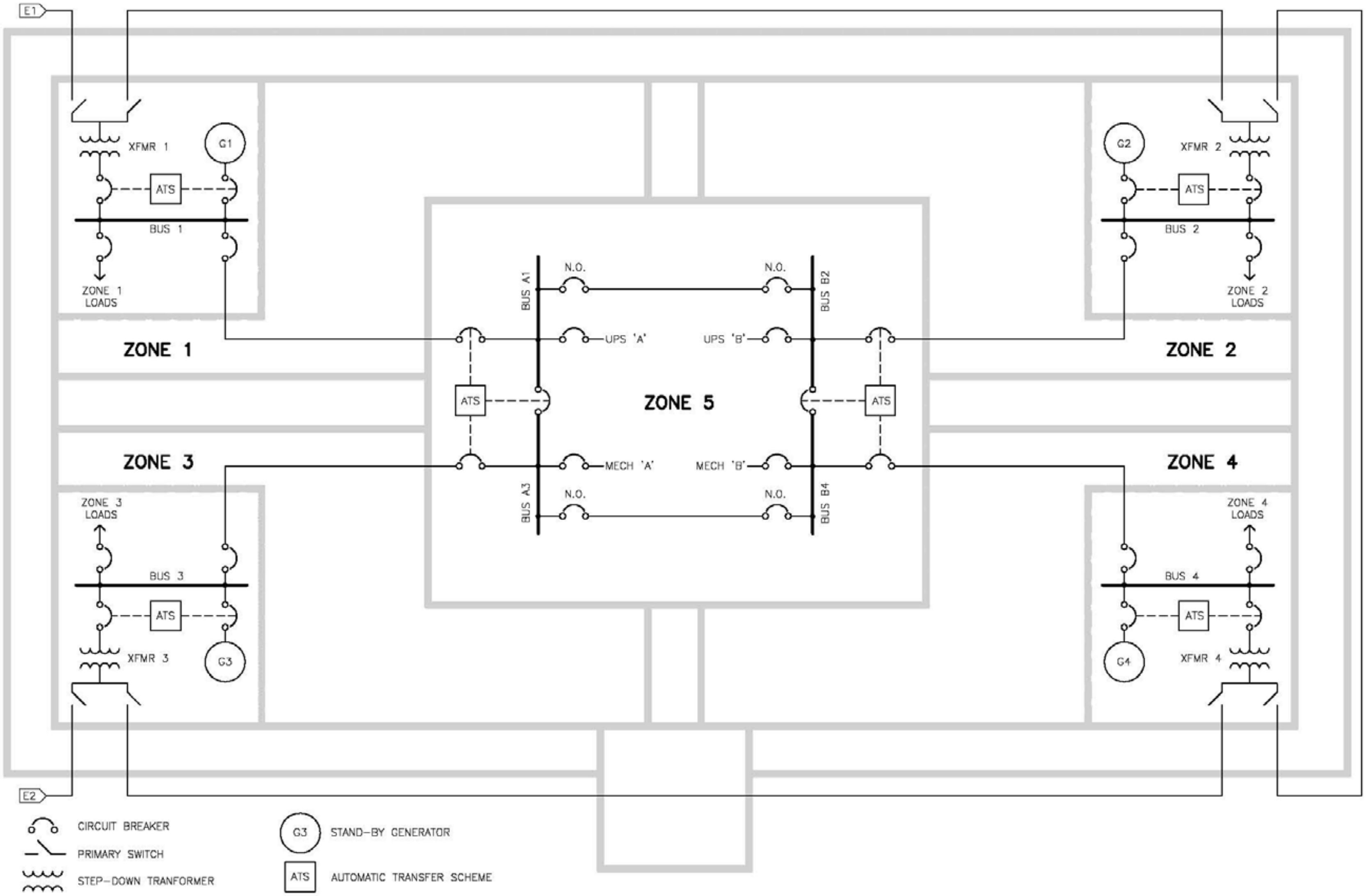

Figure 5-1. Example facility single-line diagram

a. It is assumed that power distribution within the facility will be at 480V or higher due to the large mechanical loads. Such systems, where ground fault protection (GFP) is required, should be designed as 3-phase, 3-wire systems without line-to-neutral loads. This simplifies the GFP schemes and reduces the probability of nuisance tripping. If line-to-neutral loads, such as 277V lighting, must be served, dedicated distribution for them should be provided by separate isolation transformers. This is a particularly valuable design approach for systems such as this, having load transfer downstream of the feeder circuit breakers; if the distribution were a 4-wire system, the large number of neutral tie points would lead to extremely complicated GFP schemes.

b. Within each peripheral zone, feeder circuit breakers must be selectively coordinated with the utility and generator source circuit breakers. This prevents a fault on a feeder within the zone from interrupting service from that zone to the command center. Generator current decrement characteristics must be considered to maintain the selectivity attained for operation from the utility when operating from the higher source impedance of the generator. The number of levels of GFP should correspond to the number of levels of phase overcurrent protection.

c. For the command center service configuration shown, feeder circuit breakers from the main buses to the mechanical and UPS loads must be selectively coordinated with the main circuit breakers on each incoming service. If possible, each main circuit breaker within the command center should also be coordinated with the circuit breaker on the other end of that circuit in the peripheral zone. This prevents a feeder breaker failure within the command center from causing a trip of the supply circuit, which could be misread by the supervisory control and data acquisition (SCADA) controls as an outage and could lead to automatic transfer of the faulted bus to the other supply circuit.

5-5. Grounding and surge protection

Grounding and surge voltage protection of power circuits within the facility is critical to preventing electrical transients, generated naturally or as a threat, from presenting a common-mode failure opportunity for the electrical systems.

a. Control system circuits crossing zone boundaries should use fiber optic cable to eliminate this possibility entirely. Surge protection should be installed in compliance with IEEE Standard 1100, with particular attention to effective grounding.

b. The facility should have a common ground system, designed and constructed in compliance with TM 5-690. It is neither practical nor technically sound to attempt to establish separate ground systems by zone. Rather, attention should be paid to effective bonding and to creating a low-impedance ground grid to minimize potential differences between zones across the full spectrum of surge and noise frequencies. If a single-point grounding system is used, the main ground bar should be located within the command center zone.

5-6. Physical installation

Conduits passing between the peripheral zones and the command center zone should be routed underneath the floor slab whenever possible. This decreases the number of penetrations required in the zone barrier walls, which may reduce their structural strength as well as create vulnerable points for a blast threat. Placing these conduits under the slab improves their survivability in the event that an explosion or fire event damages the interior of the zone but leaves the mechanical and electrical utility space intact. Conduits and other raceways crossing zone boundaries, regardless of routing, should be sealed to prevent the transmission of liquids or gases between zones via the conduit path. Where penetration of zone barrier walls is required, the structural engineer should be consulted for construction details to ensure that the conduit penetration cannot permit a blast wave to propagate across the boundary. Flanged, cast-in-place conduit sleeves with threaded fittings are recommended as a minimum measure to effectively seal between the wall and the outside of the conduit.

5-7. Standby generation

The capacity of standby generation for each peripheral zone should be determined as discussed in Chapter 2, Fundamentals of Limited Vulnerability Design, for the load of that zone plus the share of command center load allocated to that source under contingency conditions. Due to the constant nature of the electrical and mechanical loads in the command center, and the possibility of extended operation on standby power, engine and generator ratings should be specified on a continuous basis rather than a prime or standby basis.

a. To meet the design criteria of facility operation independent of external utilities, prime movers with fuel storage inside the secured perimeter are required. If the quantity of fuel required for the specified mission time permits, diesel engine generator sets with integral sub-base fuel tanks are a means of both meeting the internal storage requirement and providing redundancy in the fuel supply equivalent to that provided in the generators. If the mission time dictates large quantities of liquid fuel storage, fuel treatment to counter the effects of aging may become necessary. Other prime mover technologies and fuel types may also be considered if proven in standby service.

b. A consideration with respect to the routing of fuel fill and vent lines from internal storage tanks is their potential exposure to fire and explosion as well as the possibility of introducing contaminants through the lines to the tank. Fuel fill lines for tanks serving separate zones should not be grouped at a common fill station. For reliability, gravity flow is recommended from bulk tanks to engines or day tanks.

c. Air supplies used for cooling and combustion air must be protected from unauthorized access and segregated to prevent common-mode threats. The use of rooftop-mounted remote radiators greatly reduces the amount of air that must be circulated through the space housing the engine-generator, which assists with the design of blast-resistant air intakes.

d. In the example facility, it is assumed that a single standby generator is located in each peripheral zone, with a remote radiator mounted on the roof above the mechanical and electrical equipment room. This places the radiator inside the perimeter corridor, where it is relatively well protected from external threats. Air intakes for generator room cooling and combustion air and exhaust of the cooling air must also be within this rooftop area due to the presence of the perimeter corridor. These requirements must be carefully coordinated with those of the mechanical equipment to establish air flow patterns that provide adequate cooling and prevent recirculation of exhaust air into intakes. The use of heat exchangers and either well water or chilled water for engine and engine room cooling can further reduce the air intake size, albeit at the expense of increased chiller and cooling tower size.